TIDES AND COASTAL CURRENTS DEVELOPED BY TROPICAL CYCLONES

By Isaac Monroe Cline

[Weather Bureau Office, New Orleans, La., December 1931]

Personal experience in dealing with high tides and hurricane winds in the tropical cyclone at Galveston, Tex., September 8, 1900, convinced me that the tides developed by these cyclones on the coast are not only their greatest destructive agency but also one of the outstanding indicators of the intensity and extent of the storm and the place toward which it is moving. During the last 30 years my position as forecaster in charge of the New Orleans forecast center has enabled me to make an extensive study of the destructive tides that accompany tropical cyclones.

History tells us that these tides have caused enormous loss of life, such as that at Calcutta, October 5, 1864, when a storm tide of 16 feet spread over the delta of the Ganges and drowned 45,000 persons; and the Backergunge cyclone, October 31, 1876, which was attended by a tide which brought the water 10 to near 50 feet over the eastern part of the delta of the Ganges and drowned more than 100,000 persons. Great loss of life from such tides has occurred also in more recent years. Notwithstanding the fact that the great loss of life was confined to the areas flooded by the storm tides, no special study of them was attempted until recently. Meteorological students generally, it appears, had assumed that the winds in the tropical cyclone had a somewhat uniform spiral inward movement around the center of the storm area which sent the waves and swells with considerable regularity in all directions. In 1849, Colonel Reid published a diagram in which he showed the swells going out from the center of the cyclone in all directions without any differentiation as to the length and size of the swell developed by the winds in different parts of the cyclone, and as late as 1900 this diagram was reproduced as representing the movement of waves and swells developed by cyclones.

Studies of these storms and the tides which they produced soon convinced me that the great loss of life caused by tropical cyclones was not from winds directly but from drowning by the tides developed by the winds, and furthermore that the storm tide does not occur except in the right-hand front of the cyclone. I asked the Chief of the Weather Bureau in October 1919 for authority to collect the automatic tide records and meteorological and other data which had been recorded in tropical cyclones from 1900 to date and make a study under the heading, "Relation in changes in storm tides on the coast of the Gulf of Mexico to the center and movement of hurricanes." Professor Marvin, Chief of the Weather Bureau, authorized me to proceed with the study and added "I do not want you to stop when you show the relation of the tide on the coast to the center and the movement of the hurricane; I want you also to show the physical forces in the cyclone which produce these tides."

Professor Marvin's instructions made it necessary that the actual directions of the winds and the physical forces in the cyclone which produce the tides be determined. To accomplish this it was necessary to use a new form of statistical analysis in the study of the phenomena of the cyclone. The integration method, which had been used by engineers in extending their flood statistics far beyond the available experience, was used in making this study. This method enabled me to get a much more complete and precise picture of the cyclone action and the distribution of the phenomena around the center of the cyclone than was possible with the use of simultaneous observations from widely scattered stations. Important characteristics of the cyclone noted in connection with this study, not brought out by previous methods of analysis of the data, are: That the winds in the right-hand rear quadrant of the cyclone have a direction which is mainly the same as that in which the cyclone is traveling, and that they continue so during the life of the cyclone. These winds form an air stream which persists in the right-hand rear quadrant of the cyclone with wind velocities of 40 to 100 miles per hour, covering a distance of some 200 miles, and in some instances tail end winds of 20 to 30 miles per hour extend farther in the rear giving this air stream a length of something like 300 miles. These winds, with a fetch of 200 to 300 miles over water, develop waves and swells in that part of the cyclone of much greater size and length than those developed in its other portions where the winds are constantly changing direction and therefore have only a limited fetch over which to develop waves and swells.

The storm tides which build up on the coast in the right-hand front of the cyclone result from the transfer of water to shore by the storm swells which are sent out by the winds which form the air stream in the right-hand rear quadrant of the cyclone. The waves and swells developed in that part of the cyclone range from 20 to 50 feet in height, as determined by the velocity of the wind. Waves and swells so developed move forward with a velocity only a few miles per hour less than the velocity of the winds which produce them. The speed of some of these waves and swells is more than 40 miles per hour while that of the cyclone may be only 12 to 15. At such speeds the waves and swells soon move through the right-hand half of the cyclone and after passing out of the cyclonic area travel on with little change of speed and reach the coast far in advance of the arrival of the storm.

In the tropical cyclone of September 26–30, 1915, we had a fine example for showing the building up of the storm tide on the Gulf coast. At Galveston, Tex., and Burrwood, La., there was a storm tide of 0.8 foot at 8 p.m. September 26. The center of the cyclone was then south of western Cuba, approaching the Yucatan Channel, but 800 miles distant from the coast on which the tide had made its appearance 3 days before the arrival of the cyclone itself. At 8 a.m. September 27 the storm tide was 1 foot from Galveston to Burrwood and had commenced rising at Fort Morgan, Ala. The storm center passed through the Yucatan Channel during the night of the 27th–28th and at 8 a.m. of the 28th there was a storm tide of 1.5 feet from Galveston to Burrwood. There was no further rise in the storm tide on the Texas coast, but at 8 p.m. of the 28th it had risen to 1.7 feet at Burrwood, La., and had extended to Fort Morgan, Ala. From 8 p.m. of the 28th to 2 a.m. of the 29th there was a rise of 1 foot in 6 hours at Burrwood, bringing the storm tide up to 2.7 feet and in the following 6 hours ending at 8 a.m. of the 29th there was an additional rise of 1 foot, bringing the storm tide at Burrwood up to 3.7 feet.

The rise in the storm tide extended well eastward on the Florida coast but there was no rise in the tide west of Isle Dernier 25 miles to the left of the path followed by the center of the cyclone. After passing through the Yucatan Channel the storm slowly curved toward the east and its center moved inland on the Louisiana coast between Burrwood and Isle Dernier. An interesting fact is that after the storm center passed through the Yucatan Channel into the Gulf of Mexico, 8 a.m. September 28, nearly 36 hours before it reached the Louisiana coast, there was no further rise in the storm tide on the coast to the left of the point where its center moved inland but there was an additional rise of 3.5 feet at Burrwood to the right of the center, and farther to the right of the center the rise was more marked. There was no sudden and decided rise in the tide on the coast as the storm center passed inland. The greatest rise in the storm tide was about 40 miles to the right of the line followed by the storm center.

There are times when the storm tide furnishes the only concrete evidence from which conclusions can be drawn relative to changes which are taking place in the intensity of the cyclone and the direction of movement of the cyclonic center. The tropical cyclone of September 2–14, 1919, was a striking example of this nature. From 8 a.m. September 11 to 8 a.m. September 12 the cyclone moved slowly through the eastern Gulf of Mexico, and developed a storm tide of 1.7 feet at Burrwood, La., and 0.7 foot at Galveston, Tex., which indicated that the center was moving toward the mouth of Sabine Pass. However, at 8 p.m. on the 12th a shift in the rise in the storm tide appeared with a rise of 0.9 foot at Galveston and only 0.2 foot at Burrwood. At 8 a.m. September 13 a storm tide of 2.6 feet at Galveston and only 2.4 feet at Burrwood showed that the storm center was then moving toward the Texas coast to the west of Galveston. In the 12 hours ending 8 p.m. September 13 the storm tide remained stationary at 2.4 feet at Burrwood while there was a rise of 1 foot at Galveston, bringing the storm tide up to 3.6 feet at that place. At 3 a.m. September 14 Galveston had a storm tide of 7.7 feet, a rise of 4.1 feet in 7 hours. (Galveston at this time was 110 miles to the right of the line along which the cyclone center was advancing.) The storm tide rose 4 feet during the 7 hours ending at 3 a.m., September 14, which indicated that the storm center was moving toward a point on the coast to the south of Corpus Christi and that the Texas coast west of Galveston would get hurricane winds and destructive storm tides. After 3 a.m. September 14 there was no further rise in the storm tide at Galveston but it continued rising at Corpus Christi, reaching 6 feet at 8 a.m., stood at 16 feet from 4 p.m. till 6 p.m. during which time the storm center moved inland a short distance to the south of Corpus Christi, and then dropped to 6 feet at 8 p.m. These tide changes indicated the direction of movement and the intensity of the cyclone very clearly.

The barometer changes along the Texas coast were not so clear in showing the intensity and movement of the cyclone The barometer at Galveston at 8 a.m. September 13 was 29.79 inches, and at 8 p.m. 29.68 inches; on the 14th at 8 a.m. the barometer at Galveston was 29.60, the lowest recorded at that place during the passage of the cyclone. The barometer fell 0.11 inch while the storm tide rose 1 foot in the 12 hours ending 8 p.m. of the 13th, and the barometer fell only 0.08 inch while the storm tide rose 5 feet during the 12 hours ending 8 a.m. of the 14th. Here we have a total fall in the barometer of 0.19 inch at Galveston during the 24 hours preceding the passage of the storm center while the storm tide during the same time rose 6 feet. The storm tide indicated the movement and intensity of the cyclone notwithstanding its center was passing more than 100 miles distant to the left of Galveston.

At Corpus Christi, Tex., the barometer at 8 p.m. of the 13th was 29.67 inches and at 3 a.m. of the 14th 29.56 inches, showing a fall of 0.11 inch while the storm tide rose 4 feet during the same period. During the 12 hours ending 8 a.m. on the 14th the barometer fell 0.30 inch while the storm tide rose 6 feet. The center of the cyclone moved inland to the west of Corpus Christi leaving that place about 45 miles to the right of the line along which the center of the cyclone advanced. This placed Corpus Christi in the most severe part of the cyclonic area.

Another good example in which the storm tide stood out distinctly was the tropical cyclone of June 16–22, 1921, which moved inland on the Texas coast near Corpus Christi with its center passing a little to the right of that place, curving slowly toward the east. The storm tide showed up in that vicinity before the barometer at Corpus Christi commenced falling. A special observation from Corpus Christi at 4:40 p.m. June 21, showed the barometer somewhat higher than it was at 8 a.m. the same day, heavy rain falling with a maximum wind velocity of 48 miles per hour (such winds are not unusual at that place) and a storm tide of 4 feet at Corpus Christi Pass. This tide indicated that a disturbance of considerable intensity was approaching Corpus Christi at that time. No ships had encountered this disturbance during its passage from Yuctan across the Gulf of Mexico and the tide at Corpus Christi Pass was the first definite indication that a disturbance in the nature of a tropical cyclone was approaching that locality.

The development of coastal currents by the swells sent out by the winds of the right-hand rear quadrant of the cyclone is another factor of special interest in connection with erosion and enginerring projects. In the building up of the storm tide powerful currents are developed which run coastwise from right to left across the right-hand front of the cyclone. In the tropical cyclone of August 14–17, 1915, the center of which moved inland a little distance to the west of Galveston, Tex., the Trinity Shoals gas and whistling buoy, the the weight of which was 21,000 pounds, anchored with a 6,500-pound sinker and 252 feet of anchor chain weighing 3,500 pounds (total weight 31,000 pounds), was carried 8 to 10 miles coastwise to the westward of its location in latitude 29°07′ N. and longitude 92°15′ W. This buoy was anchored in 42 feet of water and was 100 miles to the right of the path followed by the center of the cyclone. Galveston Bar gas and whistling buoy with the same individual and total weights as the above, anchored at the end of the Galveston jetties in 36 feet of water was carried 4½ to 5 miles coastwise in a southwesterly direction. This buoy was located about 20 miles to the right of the path of the center of the cyclone. Another gas and whistling buoy the same size as the above, located on Heald Bank 20 miles off the entrance to Galveston Bay and to the left of the line followed by the center of the cyclone was not moved but the lights were extinguished.

Another instance of this nature was brought out in the tropical cyclone of September 6–14, 1919, which moved westward across the Gulf of Mexico and passed inland with the path of its center about 45 miles to the west of Corpus Christi. This disturbance developed coastwise currents running almost parallel to the line of advance of the storm center but they did not show the power equal to those which run across the right-hand front of the cyclone. Trinity Shoals gas and whistling buoy, already described, was 125 miles to the right of the line followed by the center of the cyclone and was moved 2½ miles to the westward. Galveston Bar buoy, already described, was 110 miles to the right of the line followed by the center of the cyclone and was carried 1½ miles to the south-west. Aransas Pass gas and whistling buoy, weight 8,000 pounds with an anchor weighing 5,000 pounds and 252 feet of anchor chain weighting 3,528 pounds (total weight 16,528 pounds) in 42 feet of water was carried 5 miles across the right front and somewhat in toward the coast. This buoy was located in latitude 27°50′ and longitude 97°02′ about 50 miles to the right of the line followed by the center of the cyclone.

The destructive power of the storm swell is brought out in this cyclone. At Sabin Bank Light House, about 125 miles to the right of the line followed by the center of the cyclone, cast iron plates five eighths inch thick, 27 feet above the surface of the water, were bent up and crushed in by the storm swells.

Currents developed by a tropical cyclone when approaching the coast run across the right-hand front of the storm in toward the coast and contribute to the building up of the tide which is the destructive feature on the coast. In cylcones traveling coastwise, currents of considerable force are developed more than 125 miles to the right of the path of the center of the storm and run nearly parallel to the coast.

A BRIEF STUDY OF OREGON TEMPERATURES

By Edward Lansing Wells

[Weather Bureau Office, Portland, Oreg., June 1931]

[Read at the meeting of the American Meteorological Society, Pasadena, Calif., June 17-19, 1931]

Four factors are prominent in the control of temperature in Oregon, namely, latitude, altitude, nearness to the ocean, and local topography. Of these factors nearness to the sea is the most important, and altitude comes next. While the State extends through more than 4° of latitude, it is probable that when everything is taken into consideration local topography will be found to be almost as important as latitude.

For this reason no discussion of Oregon temperature will be complete without reference. to the geographical and topographical features of the State.

Oregon lies mostly between the forty second and forty sixth parallels, or in the latitude of northern Italy and southern France. It extends from the Pacific Ocean inland for 375 miles. The area is 96,699 square miles, including more than 1,000 square miles of water surface. This is an area greater than that of New England, New Jersey, Maryland, and Delaware, taken together.

In altitude it ranges from sea level to more than 12,000 feet. Within the city of Portland alone there is a range of more than 1,000 feet, or more than in the combined States of Illinois and Indiana.

The most prominent topographical feature is the Cascade Range of mountains, extending from north to south. with a little less than one third of the area lying to the westward. This range includes several snow-clad peaks, the highest of which, Mount Hood, rises to an elevation of 11,225 feet. The only low pass through the Cascades is the one formed by the Gorge of the Columbia River, at the northern boundary of Oregon. This gorge is cut through nearly to sea level. It is known around the world for its beauty and for its utility in providing an all-year gateway for water, rail, highway, and air transportation. It also forms a remarkable gateway for the transportation of weather, and is one of the most interesting out-door meteorological laboratories in the world.

Next in importance is the Coast Range, extending near and parallel to the coast. For most of its length this range is relatively low, but toward the south it includes some high, rugged country, and is partially connected with the Cascade Mountains by a stretch of rough, hilly country. Within this hilly region there are numerous sheltered valleys, but no wide expanses of open country. Toward the north the Cascades and Coast Range are separated by the broad Willamette Valley, which is in itself a series of connected valleys.

The term "Blue Mountains" is rather loosely applied to a group of irregular mountain masses covering much of the northeastern quarter of the State, but in that quarter there are some broad valleys and much rolling agricultural land.

The southeastern quarter of the State is largely a great plateau, 4,000 to 5,000 feet above sea level, but from this plateau several mountain groups rise, and there are several lakes, mostly shallow and brackish, which have some local effect on climate. There are a few deep canyons, but streams are few and mostly small, losing themselves in flats or marshes, or emptying into lakes having no outlets.

The Japan current has long been given unwarranted credit for the mild climate of western Oregon. However, the marine influence is the prime factor in the control of temperature west of the Coast Range, an important though less evident factor in the Willamette and other western valleys, and a less important but noticeable factor east of the Cascades.

Fortunately in the latitude of Oregon westerly winds predominate, and therefore the modifying effect of the ocean is greater than it would be otherwise. On the rather rare occasions when strong east winds blow the continental influence may extend to the coast. Such occasions are all the more noticeable because they are unusual.

Considering only places where reliable records have been kept, the normal annual temperature ranges from about 56° in the lower Snake River Canyon, in the extreme northeast, to about 38° in the high Cascade Mountains. There are of course areas higher than any of the meteorological stations, which have still lower temperatures.

As shown at recording stations, the range in annual temperature is greater than that found in going from Mobile, Ala., to Boston, Mass., or along the immediate coast from California to Alaska. The mean temperature of the warmer sections is like that of northern Texas, while that of the cooler portions compares with that of extreme northern Montana. In all parts of the State there are marked local differences in temperature. Even within the city limits of Portland there are found, at times, pronounced differences in temperature within a few blocks.

While these differences in normal annual temperature are striking, a description of them falls very far short of telling the whole story of temperature distribution. For example, Brookings, in the southwestern corner, and Pendleton, near the northeastern corner, have the same normal annual temperature, but at no time in the year are conditions at the two places similar.

Comparison of the normal minimum temperatures for January gives a measure of the relative severity of the